Jarring/jolting exposure and musculoskeletal symptoms among farm equipment operators

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Abstract

Vehicle vibration exposure has been linked to chronic back pain and low back symptoms among agricultural tractor drivers. The objectives of this study by the National Institute for Occupational Safety and Health (NIOSH) were to assess driver whole body vibration (WBV) exposures and recommend interventions to reduce the risk of back related injuries, particularly relative to vehicle jarring/jolting (the transient mechanical shock components of WBV). The methodology included collecting, from two independent samples, field data and health and work history data of farm equipment operators. Data were collected during mowing, raking, baling, chiseling, tilling, and road travel for different model tractors. Spraying using a sprayer and shrub removal with a skid steer loader were also included. Based on ISO 2631 (1985), the American Conference of Governmental Industrial Hygienists, threshold limit values, presents $0.5\,m/s^2$ as the action level recommended by the Commission of European Communities for overall weighted total RMS acceleration (vector sum for axes x, y, and z) [ACGIH, 2006. Threshold limit values and biological exposure indices. Cincinnati, OH]. WBV measured at the operator/seat interface exceeded this action level. The roughest rides and highest vector sum accelerations occurred with small utility tractor mowers (3.3 and $2.8\,m/s^2$) and a skid steer loader ($1.7\,m/s^2$). Major findings from health and work history data showed 96% of participants reported having to bend or twist their necks, although 24% reported neck symptoms. Sixty four percent of participating operators reported experiencing back symptoms (e.g., pain, aching, stiffness, etc.). Recommendations included: specifying a seat that "better" isolates operators from jars/jolts with new tractor purchases; maintaining the seat/seat suspension and replacing worn or damaged cushions with NIOSH tested viscoelastic foam padding; using larger diameter tires with radial ply instead of bias ply construction, particularly on small utility tractor mowers, to aid in attenuating ride "roughness"; using a swivel seat to reduce the stress on the neck from bending or twisting; and improving efforts to educate owner/operators of the adverse effects of WBV exposures. Since the data presented in this paper were collected from two independent samples, the authors were unable to draw any correlations or etiological inferences from the study. However, results were compared and contrasted with other studies which included similar vibration measurements in agriculture.

Relevance to industry

Studies concerning agricultural tractor drivers have shown that vibration exposure and duration of exposure are associated with lifetime, transient, and chronic back pain and low back symptoms. The results from the field measurements and health and work history data are useful for the U.S. agricultural industry to help reduce back injury risk for farm equipment operators.

1. Introduction

Farm tractors and other earth-moving equipment contribute to some of the most common, prolonged, and severe occupational exposures of vehicle vibration among

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equipment operators. The recognition of potential hazards has resulted in standards concerned with the vibration transmitted by the seats (ISO 5007, 2003) of these vehicles and the vibration exposure (ISO 5008, 2002) of vehicle operators (Griffin, 1990).

Exposure to whole-body vibration (WBV) and the postural requirements of the job have been identified as important risk factors in the development of musculoskeletal disorders (MSD) of the spine among workers exposed to a vibratory environment (Kittusamy and Buchholz, 2004; Kittusamy, 2002, 2003; Bovenzi and Zadini, 1992; Johanning, 1991; Bongers et al., 1988, 1990). Several investigators (Wikstrom et al., 1994; Seidel, 1993; Hulshof and van Zanten, 1987; Seidel and Heide, 1986) have reported on the adverse health effects of WBV. NIOSH compiled a comprehensive body of epidemiological research presenting risk factor exposures for MSD, such as repetition, force, posture, and WBV (Bernard et al., 1997). Acute health effects include loss of visual acuity, postural stability and manual control; whereas chronic health effects include low-back pain, early degeneration of the spine, herniated discs, and digestive and circulatory disorders. Long-term exposure to WBV may also contribute to disorders of female reproductive organs and disturbances of pregnancy (Seidel, 1993; Seidel and Heide, 1986). Furthermore, WBV may synergistically affect the development of noise-induced hearing loss (Seidel, 1993).

Pope et al. (1998) studied the relationship between WBV and low-back pain. Their WBV data showed that the human spinal system has a characteristic response to vibration inputs in a seated posture. From experiments using percutaneous pin-mounted accelerometers, they determined resonances at fairly uniform frequencies for all subjects tested, first within a band of 4.5–5.5 Hz and subsequently in the 9.4–13.1-Hz range. They concluded posture, seating, and seat-back inclination affected the frequency response and that rocking of the pelvis essentially determined the response.

This paper reports on the agricultural portion of a research project done under the National Occupational Research Agenda (NORA) sponsored by NIOSH. NORA is a collaborative program to stimulate innovative research in workplace safety and health. The main goal of the overall research project was to quantify the extent and effects of vehicle jarring/jolting to reduce injury risk for operators of mobile equipment in agriculture and construction industries.

1.1. *Relevance to Industry*

A substantial portion of the research gives evidence of a strong association between WBV exposure and back disorders. Studies concerning agricultural tractor drivers have shown that vibration exposure and duration of exposure are associated with lifetime, transient, and chronic back pain and low-back symptoms (Bovenzi and Betta, 1994; Boshuizen et al., 1990a, b). Thus, the field data with the health and work history data are useful information for the US agricultural industry to help reduce MSD injury risk for farm equipment operators.

2. Methods

Vibration data were measured at selected field sites. Weighted vertical accelerations were calculated with the results plotted and superimposed on the ISO 2631 (1985) exposure time limit curves in hours. Health and work history data were collected from farm equipment operators at a major farming convention and served as a means for describing the injury issues for these operators and for identifying probable causes of these injuries. A body map was used as a tool to help participants identify body part locations where they experienced musculoskeletal symptoms.

2.1. *Field data collection*

For most of the field data collection, NIOSH collaborated with The Pennsylvania State University (Penn State) in University Park, PA. Penn State offered a wide variety of farms, farm operations, terrain conditions, and equipment from which to collect data on the effects of equipment operator exposure to vehicle jarring/jolting. A jar or jolt can be generally defined as the transient mechanical shock component of WBV that occurs when vehicles travel over irregular surfaces and can result in a "rough" ride. The farm operations comprise: (1) Agronomy Farm, (2) Operations and Services Farm, (3) Horticulture Research Farm and (4) Animal Facilities Farm. Because of its tractor inventory and different farm operations, the Agronomy Farm was selected, primarily, and secondarily, the Operations and Services Farm to collect data.

Vibration exposure data were collected on class 1 tractors with an un-ballasted maximum weight of 3600 kg and class 2 tractors with an unballasted weight range from 3600 to 6500 kg. Both classes are the most commonly used sizes of agricultural tractors. In addition to tractors, data were collected on a sprayer, and skid-steer loader. The different operations included mowing, baling, chiseling, ground working, raking, shrub removal, spraying, and road travel with a transition from smooth surface to dirt or gravel. Examples of various farming operations are shown in Figs. 1–4.

Vibration measurements were recorded with an 8-channnel, digital data recorder (model PC208Ax, Sony Manufacturing Systems America, Lake Forest, CA). Other instrumentation (PCB Piezotronics, Inc. Depew, NY) included triaxial accelerometers (models 356B18, 356B40), signal conditioning amplifiers (model 480E09), and in-line, 150-Hz low-pass filters (model 474M32). The floor or frame-mounted accelerometer featured a frequency range of 0.3 Hz to 5 kHz and a charge sensitivity ranging from 949 to 1052 mV/g for the three directional axes. The seat

Fig. 1. Class 2 tractor baling hay.

Fig. 2. Class 2 tractor mowing a field.

pad accelerometer featured a frequency range of 0.5 Hz to 1 kHz and a charge sensitivity ranging from 97.4 to 105 mV/g for the three directional axes. The frame accelerometer was secured with magnetic mounts to the floor of the operator's compartment near the base of the seat (frame measurement). The seat pad was secured to the seat with duct tape and directly sat upon by the equipment operator (seat measurement). Vibration data were generally collected for about 30 min and were used to quantify the vibration energy transmitted to the seat through the workstation platform from the vehicle chassis or frame.

The raw data were initially viewed in terms of root-mean-square (RMS) acceleration, peak acceleration (for jars/jolts), and crest factor (ratio of peak acceleration/RMS). Of these variables, peak acceleration and crest factor were the most descriptive relative to jars and jolts, although RMS acceleration is necessary to compute the crest factor. Further, the data were analyzed according to ISO 2631 (1985) exposure limit (weighted vertical or *z*-axis direction) and total overall weighted RMS acceleration, a single-value computation for all three directions of vibration.

2.2. Health and work history data collection

The 2003 American Farm Bureau Federation (AFBF) Annual Meeting and Convention provided the forum for collecting health and work history data from attendees who operated farm equipment. To recruit participants for this study, an ad was placed in the AFBF convention newsletter and a display booth was set up in the section designated for exhibitors. Respondents were volunteers who passed by the booth, signed up to participate, and were subsequently organized into small focus groups. An instrument, adapted from Kittusamy (2003), was used in focus groups to gather general information, work information, job history, information on currently or recently operated equipment, medical history, exercise and hobbies information, injury history, and history of injury symptoms. Historical musculoskeletal symptoms (within the last 12 months) were identified by body part location and collected using a body map instrument (Fig. 5). Data were tabulated and analyzed using SPSS software.

3. Results

3.1. Vibration field measurements

Table 1 provides a summary of results for data analyzed from the Penn State farms. The jars/jolts showing the three largest peak (vertical) accelerations, were obtained for the road travel (33.7 m/s^2), shrub removal (13.8 m/s^2, Fig. 6), and mowing (11.3 m/s^2, Fig. 7). These peak accelerations were taken from the raw data and not weighted values. Notably, high crest factors (peak amplitude divided by the RMS value) were computed also for road travel (16.2), shrub removal (14.2), and tilling (7.3). Exposure limit times for all of the equipment and shows the lowest, 3 h, for the two small utility-type, tractor mowers (class 1). The total overall weighted RMS accelerations for all equipment operations ranged from 0.9 to 3.3 m/s^2 thus exceeding the 0.5 m/s^2 recommended action level (ACGIH, 2006). Among the highest total overall weighted RMS accelerations were those obtained for mowing (3.3 and 2.8 m/s^2), shrub removal and raking (1.7 m/s^2), and road travel (1.6 m/s^2).

3.2. Health and work history data

Fifty of 61 potential respondents (80% return rate) participated in the study. Forty-five (90%) of the participants were owner/operators, along with two (4%) workers and two (4%) managers. One person did not identify their position. Participants included 44 (88%) males and six (12%) females. The respondent's age and years of experience in operating farm equipment averaged 48 and 33, respectively. The participants operated farming equipment, on average, 24 h per week.

Most operators indicated that the cab/workstation design was satisfactory. Thirty-four (68%) responded

Fig. 3. Class 2 tractor tilling a field.

Fig. 4. Sprayer working a field.

that the seat was adjustable and 48 (96%) could easily reach and operate the pedals and levers. Moreover, 96% reported that they have to bend or twist their necks. All operators indicated that proper maintenance was performed and that repairs were performed when needed/required.

All subjects stated they could at least feel some vibration either through the floor or seat and 27 (54%) could feel vibration often or always. Even though 45 of 47 (96% of) respondents stated they had ladders or stairs present on equipment and of those 41 (91%) said the first step was 70 cm or less (ANSI/ASABE, 2006), 17 (38%) said they had to jump off equipment to exit.

Seven (14%) participants stated they operated equipment on the farm a minimum of 50 h per week. The reported types of equipment used by the participants were: various configurations of tractors (front end loaders, backhoes, etc.); forklifts; self-propelled mowers; skid-steer loaders; combines; self-propelled forage harvesters; cotton harvesters; excavators having both tracks and tires; bulldozers; and large and small trucks with some having dump beds or feeder beds. The predominant types of equipment operated were tractors, with or without attachments. The age of all of the equipment reported was predominantly older than 5 years.

Seventy-two percent of 43 participants reported musculoskeletal symptoms in various body parts. The percentage of participants who reported symptoms in a particular body part is shown in Table 2. Thirty-six percent of 43 respondents stated they missed one or more days of work. Seventeen of 43 respondents stated the injuries sustained to them had caused them to change or modify their normal activities. Twenty-eight percent had back pain that radiated to the legs for the year preceding.

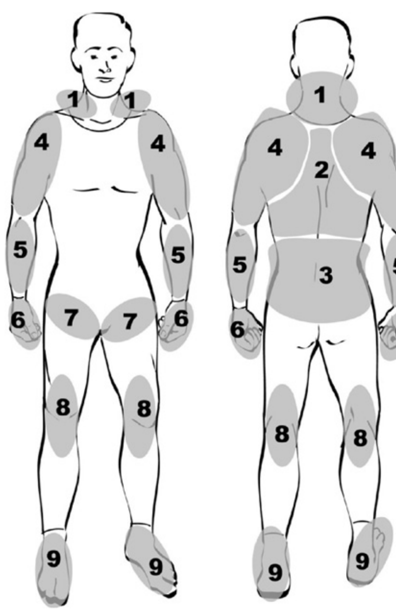

Fig. 5. Front and rear diagrams of a body map with numbered body part location (adapted from Kittusamy, 2003).

4. Discussion

The field data analysis showed vehicle operators experienced peak vertical accelerations—indicative of jars/jolts—that could reach accelerations as high as 3.4g's. This particular event occurred at the transition of two road surfaces with the vehicle traveling at a relatively higher rate of speed. A power spectral density analysis of the data reveals that this g-level corresponded to a frequency lower than the sensitivity range of the seated human body (4–8 Hz). Potentially, this magnitude could be problematic, but it is unclear to what degree that it would be. How often such events occur for the type and class of vehicle is important to note when evaluating operator exposure, severity of exposure, and needed isolation for the seat and possibly other operator cab components. The authors observed that these occurrences were not frequent during data collection. However, owing to the complexities

Fig. 6. Skid steer loader during shrub removal operation.

Table 1
Peak acceleration (nonweighted) and crest factor in vertical (z direction), exposure limit in vertical or z direction, and overall total weighted RMS acceleration (3 directionsal vector sum) for different farm equipment

Equipment	Class	Actual ballasted weight (kg)	Operation	Peak vertical acceleration (m/s^2)	Crest factor[a]	Exposure limit[b] (h)	Vector sum[c] (m/s^2)
Tractor	1	746[d]	Mowing	11.25	4.91	3	2.84
Tractor	2	5386	Mowing	2.93	3.88	24	0.87
Tractor	1	965	Mowing	10.13	4.43	3	3.26
Tractor	1	2395	Raking	9.20	6.06	5	1.70
Tractor	2	5386	Baling	3.72	6.07	24	0.86
Tractor	1	5691	Baling	2.41	3.42	12	1.03
Tractor	3[e]	6909	Chiseling	4.55	5.22	20	1.33
Tractor	2	5386	Tilling	7.88	7.25	11	1.51
Tractor	1	2395	Road	33.69	16.18	6	1.56
Sprayer	2	6773	Spraying	5.92	6.56	17	0.96
Skid steer loader	2	3932	Shrub removal	13.75	14.18	11	1.73

[a]Crest factor is dimensionless.
[b]ISO 2631 (1985).
[c]Vector sum represents overall total weighted RMS acceleration.
[d]No ballast.
[e]Data taken at privately owned farm near Pittsburgh, PA USA.

Fig. 7. Class 1 utility tractor mowing a field.

Table 2
Summary of respondents reporting musculoskeletal symptoms according to affected body part

Body part	Respondents reporting symptoms (%)
Low back	38
Wrist/hand	28
Knee	28
Ankle/foot	28
Middle/upper back	26
Neck	24
Shoulder/upper arm	24
Elbow/forearm	16
Hip	12

of collecting data in the field, it is not clear how often these conditions could occur and what the cumulative effects of such exposure may have on injury risk.

Crest factors exceeding six were noted for raking, baling, tilling, spraying, shrub removal and road travel. In the latter two cases, the crest factors were more than double the ACGIH (2006) TLV guideline based on ISO 2631 (1985). The guideline states that the TLVs are not adequate for evaluating a vibration environment characterized by high-amplitude mechanical shocks (jars or jolts) and it will "underestimate the effects of WBV …when crest factors exceed 6." ISO 2631 (1997) stipulates that the crest factor may not always indicate severity of vibration and refers to a crest factor of nine as compared to six noted above.

The data analysis for the two small, utility-type, mower tractors (class 1) showed the lowest recommended exposure times of 3 h (based on an 8-h day); whereas the class 2 vehicles showed the highest peak accelerations. It is believed that the lower ISO 2631 (1985) recommended exposure time limit of 3 h for the class 1 compared to the class 2 vehicles results from the class 1 vehicle having: a lower mass and shorter wheel base 142–165 cm; smaller diameter tires with, e.g., radial- versus bias-ply tire construction; and a lower grade/cost seat with fewer features (e.g., small displacement from seat suspension) for isolating against vehicle vibration and jars/jolts. These factors contribute to a generally rougher ride for the class 1 vehicle. Also, the class 2 vehicles (with greater mass and usually better seating) are intended for use in more "heavy duty" service (raking, baling, tilling, etc.) over generally rougher ground.

The total overall weighted RMS accelerations for all equipment operations exceeded the 0.5 m/s^2 8-h action level recommended by the European Commission (ACGIH, 2006). The order of magnitude ranged from 1.7 to 6.5 times. These values show the potential for adversely affecting the long-term health of these machinery operators performing the selected dynamic activities.

Several studies have investigated WBV exposure in farming for tractor drivers (Lines et al., 1995; Sorainen et al., 1998; Kumar et al., 1999, 2001; Muzzammil et al., 2004; Scarlett et al., 2007). Scarlett et al. (2007) quantified WBV levels and estimated operator exposure for a range of modern state-of-the art tractors under controlled "in-field" conditions and actual "on-farm" use. The operations studied included ploughing, plough transport, cultivating, and trailer transport. Farm equipment included a range of medium to large (90–130 kW) four-wheel drive tractors that were characterized as unsuspended, suspended cab, suspended front axle and cab, and fully suspended (front and rear axle). The ISO 5008 (2002) methodology was used for the controlled test conditions. They considered European Physical Agents Directive: 2002 in the study from the premise of potential consequences of operator WBV limitations. Results of the controlled tests showed greater differences in WBV levels between target operations than between different tractors (i.e., suspension systems) performing the operations. Magnitude of WBV, cultivating generated high WBV levels (RMS of 1.50 m/s^2) opposed to spraying which generated low levels (RMS of 0.75 m/s^2). Tractors in the NIOSH study were considerably smaller in size, particularly the utility tractor mowers, although the tasks concerning cultivating and spraying were similar. NIOSH results, though not directly comparable using ISO 2631 (1985) method, showed similar indications of WBV levels with higher vector sum values 1.50–1.60 m/s^2 for chiseling and tilling (cultivating) operations and lower ($<1.0\,m/s^2$) for spraying.

As in this NIOSH study, Lines et al. (1995) measured tractors and other farming vehicles during a range of normal field operations. Using both the ISO 2631 (1985) and BS 6841 (1987) methods of analysis, they concluded that most drivers were exposed to WBV levels that exceeded the safe limit for an 8-h day. Only baling and combine harvesting operations were considered safe with exposure limits of 16 and 24 h, respectively. This compares to the NIOSH study using ISO 2631 (1985) where results for the two small, utility-type, mower tractors showed the lowest recommended exposure times of 3 h, and for the larger tractors (class 1 and above), raking and road travel. Tractors performing transport tasks exhibited the highest vibration levels, whereas the NIOSH study showed highest levels for these same class 1 utility mower tractors. Crest factors from the NIOSH study were for the vertical acceleration (z) generally were lower than those recorded by Lines et al. (1995).

Health and work history data revealed musculoskeletal symptoms in various body parts for the respondents. Nearly all farm equipment operators reported having to bend or twist of the neck showing it is an essential part of pulling equipment and other machinery behind it. Whether or not performing this awkward posture leads to injury or injury symptoms would depend on how often operators assume this posture and the angular extent of turning the head. More than a third of the respondents reported jumping off equipment to exit, which may contribute to back-related and knee/ankle/foot symptoms that respondents reported with relatively high incidence. Jumping from the cab of a tractor presents a significant health risk with potentially damaging effects when considering that the impact force may be as high as 11 times the operator's body weight for a jump from cab level of a commercial farm tractor (Fathallah and Cotnam, 2000). Pain, along with stiffness, may begin after lifting a heavy object, a fall (equivalent to jumping off equipment), standing or sitting for a long time, e.g., all-day operation of farm vehicles (Bovenzi et al., 2002). Unfortunately, the data was limited in that it did not permit the authors to correlate the various injury symptoms with high-risk work practices, awkward postures, and vehicle jarring/jolting. Nonetheless, control measures or interventions to reduce the amount or degree of neck bending/twisting (e.g., a swivel seat) and educating operators to avoid jumping off equipment would be positive steps toward reducing the incidences of musculoskeletal symptoms and injury risks.

Kumar et al. (1999, 2001) investigated the effect of WBV on the low back in northern India using a retrospective cohort study of 50 tractor-driving farmers (TDF), the study group, and fifty non-tractor-driving farmers (NTDF), the control group. Subjects in the control group were matched for age, gender, generic/ethnic group, land-holding, and work routines. In addition to clinical investigations, magnetic resonance imaging (MRI) was used to assess WBV exposure and degenerative changes in the spine, while vibration measurements were done to assess vibration severity. TDF showed self-reported back pain (for last 12 months) at 24% and NTDF at 14%. This compares similarly to the NIOSH study of self-reported back symptoms at 64%-although these may not all be work-related. MRI results revealed no significant differences between the study and control groups concerning degenerative changes of the spine ($P>0.050$). Considering the area of the back, in the North India study for TDF lower back results were 75% versus 56% for NTDF compared to 38% in the NIOSH study; concerning the upper back was 13% for NTDF and 4% for TDF compared to 26%. Kumar et al. (1999, 2001) concluded that TDF reported more frequent backache than NTDF, but clinical MRI evaluations revealed no significant differences between these two groups.

NIOSH researchers noted that study participants were generally not aware of the potential effects of WBV exposure from operating farm equipment. The authors believe that knowledge of these effects may help the equipment operators to avoid or minimize injury risk and/or discomfort. Examples of this would be recognizing when attenuating properties of a seat suspension or seat padding has deteriorated or what postures should be avoided or altered during vibration exposure. Consequently, educating owners/operators to increase awareness of how WBV may affect the body and health during farm equipment operation would be a simple, yet important part in lessening injury risk.

Finally, it is helpful to comment briefly about tractor age for this study. The age distribution of the tractors was not unlike the Myers and Snyder (1995) findings that showed, in 1993, the national average age of tractors in operation was 22.8 ± 0.53 years with model years that ranged from 1924 to 1994. Similar results were found in New York State (West and May, 1998).

5. Recommendations

From observations and conversations with tractor operators and farm conference attendees, the following recommendations are offered. First, whenever possible, specify the "better" seat for new tractor purchases or seat replacement (i.e., a "better" seat with transmissibility characteristics that attenuate jars/jolts and thereby, isolate equipment operators from them). The purchaser should consult with the equipment dealer for seat manufacturer specifications on seats with good vibration attenuating characteristics. Also, farmers should keep the seats/seat suspensions well-maintained and replace worn or damaged seat padding. One consideration for replacement padding is

NIOSH tested viscoelastic foam padding which has proved effective in mining applications (Mayton et al., 2003, 1999) with vibration environments similar to those found in farming. In reviewing field data results, operators of small, class 1 utility tractor-mowers can experience rough rides with peak vertical accelerations of $11.3\,m/s^2$ and an ISO 2631 (1985) exposure time limit of 3 h. As practical, farm equipment operators are encouraged to vary tasks to reduce exposure time for tasks where higher vibration levels are encountered. In addition, a slow 10-min walk is recommended after exiting the vehicle and before performing other physical tasks to permit the low-back motion segments to reorient themselves (Wilder, 1993).

Another recommendation, particularly for the small utility tractor-mowers, is to use larger diameter tires with radial—instead of bias-ply construction to aid in attenuating ride "roughness." Intuitively speaking, larger diameter tires have greater tire height (tread to rim) that allows for greater flexing (larger travel) and more damping. Moreover, they can more easily span the distance across surface irregularities in which smaller diameter tires are prone to "bottom out." Furthermore, radial-ply, in contrast to bias-ply, tires generally possess a more flexible sidewall leading to a softer ride and show a decrease in force amplitude for frequencies below 15 Hz (Gillespie, 1992). Tire pressure is also an important factor. Given the manufacturer's recommended range of tire pressures, a "harder" tire (higher pressure) supplies less damping than a "softer" (lower pressure) one.

From health and work history data, 24% of participants indicated symptoms for the neck. Ninety-six percent of tractor operators bend or twist their neck during operations such as tilling, plowing, raking, etc. Consequently, a seat that swivels is recommended to reduce the stress on the neck caused by frequent bending and turning of the head.

Finally, health and work history and field data collection efforts revealed that study participants lacked awareness about the potential adverse effects of WBV exposure on farm equipment operators. Consequently, educating owners/operators of the effects of WBV on the operator during farm equipment operations is recommended. This can be done with safety training sessions during industry conferences and trade shows and by including such information in the owner's manual or CD for the equipment provided by the manufacturer.

6. Limitations

This study provides useful information and results in quantifying WBV exposure and musculoskeletal symptoms for farm machinery operators. However, it includes various limitations. Field data collection occurred at just three farms with a small sample size of farm equipment. The study was also limited by the difficulties and constraints that accompany field data collection and the individual driving differences among equipment operators. The measured data at the seat may not be representative of the vehicle or the task, since different vehicles generally employ seats that differ in design, construction, age and suspension and cushion properties. The health and work history results provided an initial step of basic information about musculoskeletal symptoms for farm equipment operators. Different population samples were used for measured field data and the health and work history data collection; this did not allow for cross-sectional correlation of the data. The latter data of musculoskeletal symptoms were collected at a conference and reflect "current" symptoms (within the last 12 months) that may not necessarily relate to work since participants were not at work. Since the data presented in this paper were collected from two independent samples, the authors were unable to draw any correlations or etiological inferences from the study. Moreover, it is likely that results of the health and work history include selection and recall biases. Furthermore, comparisons of NIOSH data with other similar vibration studies have limitations that include national and cultural differences associated with, among others, farming methods, tractor make, model, age, size, and ground surface, as well as individual driver preferences in driving speed, posture, and steering technique.

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